Predicting Tropical Cyclone Formation and Structure Change

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LONG-TERM GOALS

The long-term goals are to create and deliver knowledge-based expert system modules that will allow the Joint Typhoon Warning Center (JTWC) forecasters to make more accurate and consistent forecasts of tropical cyclone formation and outer wind structure.

OBJECTIVES

A tropical cyclone formation expert system module has become necessary due to the Navy requirement for five-day track forecasts. A tropical cyclone may form and reach typhoon intensity in less than five days, which may pose a threat to exercises and ship operations. Because dynamical model tropical cyclone structure and track guidance tends to be less accurate during the early stages of the tropical cyclone life cycle, the prime objective during this past year has been to identify the capability of numerical models to forecast tropical cyclone formation. This includes a geographic assessment of the potential for tropical cyclone formation, which implies that the distribution of tropical cyclone formation locations will reflect favorable synoptic-scale conditions.

APPROACH

The overall project approach is to follow the successful Systematic Approach to tropical cyclone track prediction in that knowledge, procedures, and databases for tropical cyclone formation and structure will be utilized. For the specific objective to assess numerical forecasts of tropical cyclone formation, the approach has been to objectively track and catalog analyzed and forecast low-level circulations plus relevant environmental parameters that may be related to the subsequent development or non-development of a tropical cyclone. Statistical analysis of the database created through the catalog procedure will identify factors that are related to successful and unsuccessful dynamical model forecasts of tropical cyclone formation.

WORK COMPLETED

A system has been designed and implemented that catalogs analyzed and forecast parameters (Table 1) associated with tropical vortices in operational global forecast models. Additionally, a web-based interface has been implemented to portray analyzed and forecast tracks with fields of the cataloged parameters to allow assessment of forecast model performance. The system has been applied to the 2002-2003 tropical cyclone Southern Hemisphere tropical cyclone season, and is being applied to the 2002 western North Pacific tropical cyclone season, and 2003 western North Pacific and North

Atlantic seasons. Finally, an assessment (Harr 2002) of tropical cyclone formation issues was completed for the Fifth International Workshop on Tropical Cyclones sponsored by the World Meteorological Organization.

Relative vorticity at 850 hPa (10^{-5} s^{-1})
sea-level pressure (hPa)
latent heat flux (surface) (W m^{-2})
shallow vertical wind shear (500-850 hPa) (m s^{-1})
deep vertical wind shear (200-850 hPa) (m s^{-1})
geopotential height thickness expressed as a difference from the surrounding region outside of the ellipse (1000-200 hPa) (gpm)
1000-500 hPa temperature difference expressed as a difference from the surrounding region outside the ellipse (K)
Vertical motion (Pa s^{-1})
Total precipitation (kg m^{-2})
Vapor pressure at 500 hPa (Pa)

Table 1
Model parameters defined for every analyzed and forecast circulation center that is identified and tracked.

RESULTS

As an initial investigation of tropical cyclone formation, the times of formations were compared with the forecast times as defined by official tropical cyclone formation alerts (TCFAs) during the 2002 Northern Hemisphere tropical cyclone season and 2002-2003 Southern Hemisphere season (Table 2). Eventually, model-predicted formation times will be compared with the official forecast formation times. Although the majority of cases occurred with +/- 3 h timing error, there was a tendency for formations to occur later than forecast (positive errors) over the western North Pacific and earlier than forecast over the Southern Hemisphere.

Based on analysis of the forecasts from the Navy Operational Global Atmospheric Prediction System (NOGAPS) during the 2002-2003 Southern Hemisphere tropical cyclone season, relationships have been defined between forecast parameters (Table 1) and verifying values derived from model analyses when tropical cyclone formation was forecast and it occurred. One example is that NOGAPS vorticity forecasts at the time of actual tropical cyclone formation tended to be too low (Fig. 1).

Additionally, forecast values of all cataloged parameters have been examined to identify those that have the most significant relationship with best-track defined wind speed during the course of the tropical cyclone life cycle. Results indicate that forecast vorticity and vertical wind shear consistently had the best correlation with observed 10- minute averaged wind speed. These relationships were

Basin	Count of Errors in Formation Timing (hours))											
	-30	-24	-18	-12	-6	0	6	12	18	24	30	36
Atlantic		2		3	4		1					
Pacific - East	2		2	3	7	5	5	3	1	1		
Pacific - Central						1		1		1		
Pacific - West				3	3	16	9	12	4	1	3	3
North Indian Ocean		1	1		2	2		1		1		
Southern Hemisphere	2	1	3	9	13	11	5	1				
all	4	4	6	18	29	35	20	18	5	4	3	3

- note that there is one –48 hour error for the western Pacific not shown in the table

Table 2
The time difference between the TCFA estimate of formation to the actual TC formation time (first onset of 30 knot winds) calculated and rounded to the nearest 6 hours. A negative error implies that formation occurred before the forecast formation time.

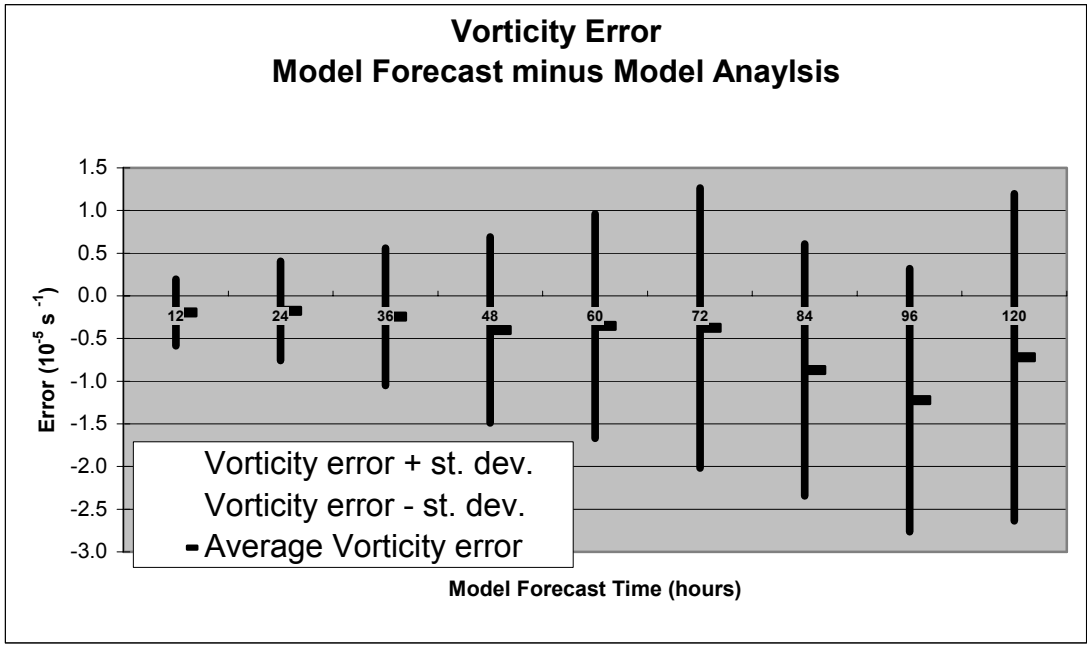

Figure 1.
NOGAPS forecast vorticity errors during the 2002-2003 Southern Hemisphere tropical cyclone season.

examined in a multiple linear regression scheme applied to a limited sample of 3 tropical cyclones during the 2002- 2003 Southern Hemisphere season. In the regression scheme, forecast vorticity and vertical wind shear were used to define the 10-minute average wind speed (Fig. 2). The r-squared values ranged from 0.64 for 24-h forecasts to 0.44 for 72-h forecasts (Fig. 2). Addition of other forecast parameters did not alter the r-squared values significantly.

Relationships between forecast parameters and best-track values will be used to define thresholds for use in assessing the potential predictability of tropical cyclone formation over each tropical cyclone basin and for each operational global forecast model.

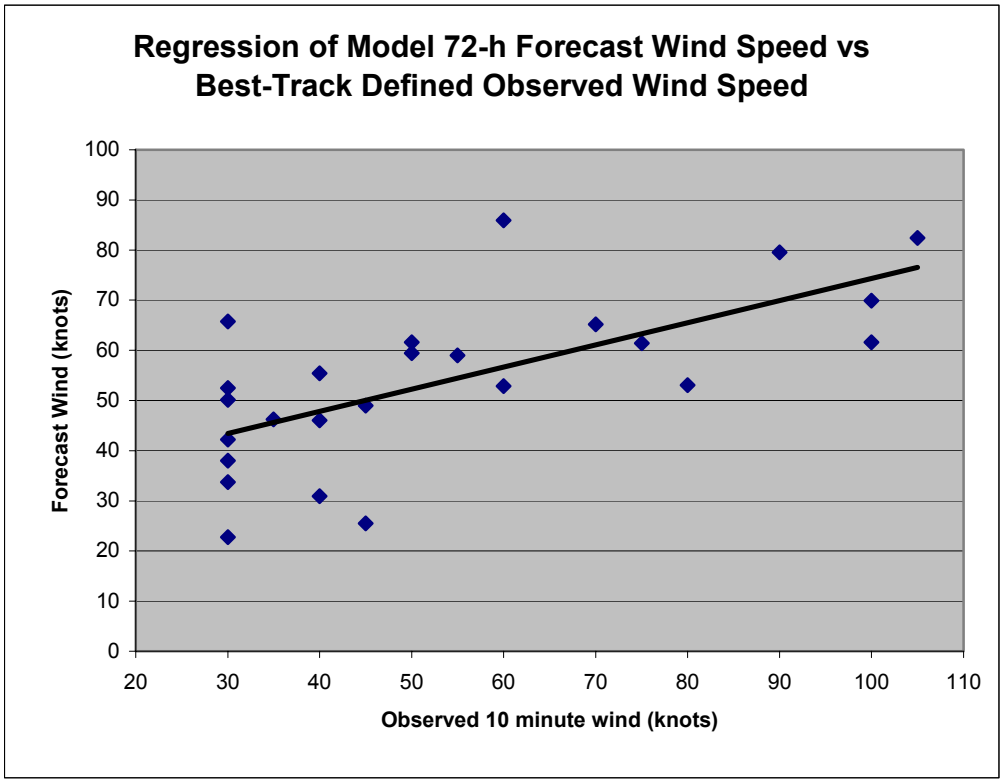

Figure 2.
Scatter plot of 72-h forecast wind speeds from NOGAPS and best-track defined 10-minute wind speeds for three tropical cyclones during the 2002-2003 Southern Hemisphere tropical cyclone season. The regression line is based on a multiple linear regression of best-track wind speed on forecast vorticity and vertical wind shear.

IMPACT/APPLICATIONS

Application of the new tracking algorithm to analyzed and forecast circulations will enable development of a knowledge-based database that is objectively and automatically generated. The data base will form the basis of an expert-system module that will assist JTWC forecasters in evaluating circulations as their potential for developing into a tropical cyclone by placing the current forecast scenarios in the context of historical model traits.

TRANSITIONS

In this project, the application of the objective tracking procedure and generation of the knowledge-based data set will be transitioned to operations as part of a comprehensive system for assessment of potential tropical cyclone formation based on dynamical model forecasts and evaluation of other real-time products (i.e., satellite imagery linked to numerical model output).

RELATED PROJECTS

This project is related to the project titled Evolution of Tropical Cyclone Characteristics, in which the tracking algorithm has been developed. Further research concerning large-scale circulation variability and mesoscale characteristics of convective systems associated with developing circulations that is being conducted in the related project will be included in the generation of the expert system module for tropical cyclone formation and structure.

SUMMARY

A prototype database that is meant to serve as the framework for an expert system module on tropical cyclone formation and structure as an aid to JTWC forecasters has been constructed. The database contains factors that relate dynamical model fields to the synoptic-scale conditions that may impact model forecasts of tropical cyclone formation. Future development will augment the database with estimates of mesoscale conditions related to convective systems associated with the developing circulations.

PUBLICATIONS

Harr, Patrick A., Tropical cyclone formation and extratropical transition. Topic Chairman and Rapporteur Reports of the Fifth International Workshop on Tropical Cyclones (IWTC-V), WMO-TD No.1137, WMO Geneva, Switzerland.